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FM HANDLING AND ANALOG-TO-DIGITAL CONVERSION OF BIOMEDICAL DATA FROM A 1,000-FLIGHT STUDY

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SUMMARY

To collect, process, and analyze FM-recorded biomedical data from 1,000 flights in high-performance aircraft and test vehicles, it was necessary to devise a handling facility that would prepare these data in a standard format for high-speed-computer processing. The handling system designed maintains the very high signal-to-noise ratio inherent in the original data-acquisition equipment, provides pushbutton control for converting the medical information into a standard format for digital processing at either four or eight times faster than the original record speed, and provides an effective number of quality-control checkpoints. The system is described in detail, and system design considerations are discussed in relation to preventing data degradation in both FM handling and digital conversion.

Approximately 1,400 hours of flight data have been processed by this system in less than 600 hours without loss of data integrity. This facility has operated successfully since October 1965 and has required only daily preventive maintenance, such as cleaning the tape decks and demagnetizing the tape heads. This system is suitable for preparing biomedical data in standard format for digital processing, since the system design can easily be changed to accommodate nonstandard input formats.

INTRODUCTION

The large amount of data obtained during a flight study at the USAF Aerospace Research Pilot School, at Edwards, Calif., (ref. 1) represents a significant portion of the NASA Flight Research Center's biomedical program to determine physiological response in a flight environment. In obtaining these biomedical data and maintaining suitable instrumentation for these purposes, the Flight Research Center used specially developed biomedical monitoring techniques and equipment on location at the school, as discussed in reference 2. The output of this monitoring effort, for data processing, was one channel of electrocardiogram (single sternal lead), one channel of acceleration, one channel of respiration rate, and a voice channel. These data were stored during flight on FM tape. Additional information, such as type of mission, pilot's name, age, weight, aircraft type, and instructor's name, was entered on a form attached to the flight recording.

To collect, process, and analyze these flight data required rigorous attention to detail in each phase in order to achieve acceptable repeatability. Consequently, early in 1964, research efforts were initiated by the Flight Research Center to develop monitoring equipment, procedures, and automatic data processing techniques for application to physiological data collected on pilots operating high-performance aircraft. By mid-1964, a realization of the facilities required was achieved, and facility design and construction was started. Now in existence are portable flight equipment and procedures vans (ref. 2), FM and analog-to-digital handling equipment, and digital reduction facilities. In handling large amounts of medical flight information recorded on tape, considerable conversion, dubbing, and other handling of the information is required before it can be reduced by using available digital computers. This handling is required because space and power limitation, which apply to recorders carried by the pilot, generally prevent recording in a standard format. This problem is universal with medical information recorded on active subjects. FM handling, unless properly designed, can significantly degrade the information obtained.

This paper describes and discusses an adequate FM and analog-to-digital handling system for biomedical data. Although the techniques are used routinely in engineering applications, they have rarely, if ever, been used before to handle medical data.

DESCRIPTION OF DATA-HANDLING FACILITIES

FM Data-Handling Facility

The FM data-handling facility was located in flight equipment and procedures vans at the Aerospace Research Pilot School where most of the 1,000 flights were monitored. This location was chosen for the facility so that the equipment could be utilized to:

1. Allow immediate quality checks on a flight-by-flight basis for verifying flight equipment accuracy and performance.

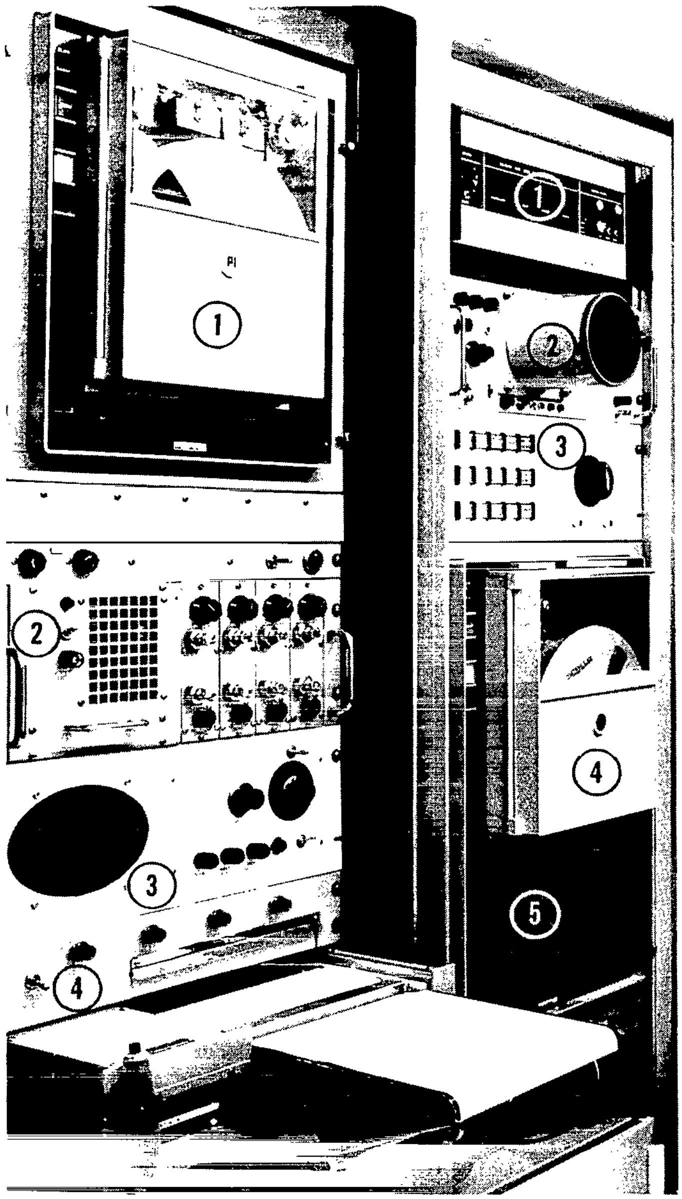
2. Allow immediate dubbing of a time code on each original flight tape, where the time-code reference is used to relate flight events to these data.

3. Conserve manpower and utilize effectively, for the operation of this facility, personnel that were otherwise busy only during periods of peak workloads, such as when pilots were being escorted to the aircraft or being instrumented or deinstrumented (ref. 3).

The primary purpose of the FM data-handling facility is to prepare analog physiological data obtained in flight for digital computations (ref. 2).

To prepare the data, it is necessary to relate all data to a time base and to present a suitable data format for analog-to-digital conversion. (The FM data format is designed to be compatible with all standard analog-to-digital conversion equipment.) Thus, the facility was designed to automatically dub a time code, play back the 1/2-inch raw (FM) data tape, and present the discriminated FM data on an oscillograph while simultaneously dubbing these data to a 1-inch, 14-channel tape, referred to as the secondary tape, used as a data source during the analog-to-digital conversion. To perform this handling procedure, two consoles (fig. 1) were constructed, each with an FM record and reproduce tape deck. Console A contains the tape deck that plays back the flight tape, and console B contains the time-code generator and records

Console A   Console B



Console A

1. 1/2-inch tape deck for playback of flight tape
2. Panel containing amplifiers for strip-chart recorder
3. Audio amplifier for voice channel
4. 4-channel hot-stylus strip-chart recorder

Console B

1. Time-code generator
2. Monitor oscilloscope
3. Master control panel
4. 1-inch tape transport
5. General-purpose junction panel

Figure 1.– The FM data-handling facility.

the secondary tape. The major components of each console are designated in figure 1. Figure 2 shows the interconnection of the major components of the FM data-handling system and the location of these components in the consoles. As shown, the 1/4-inch tape deck, used for playback of pilot comments, is external to the consoles.

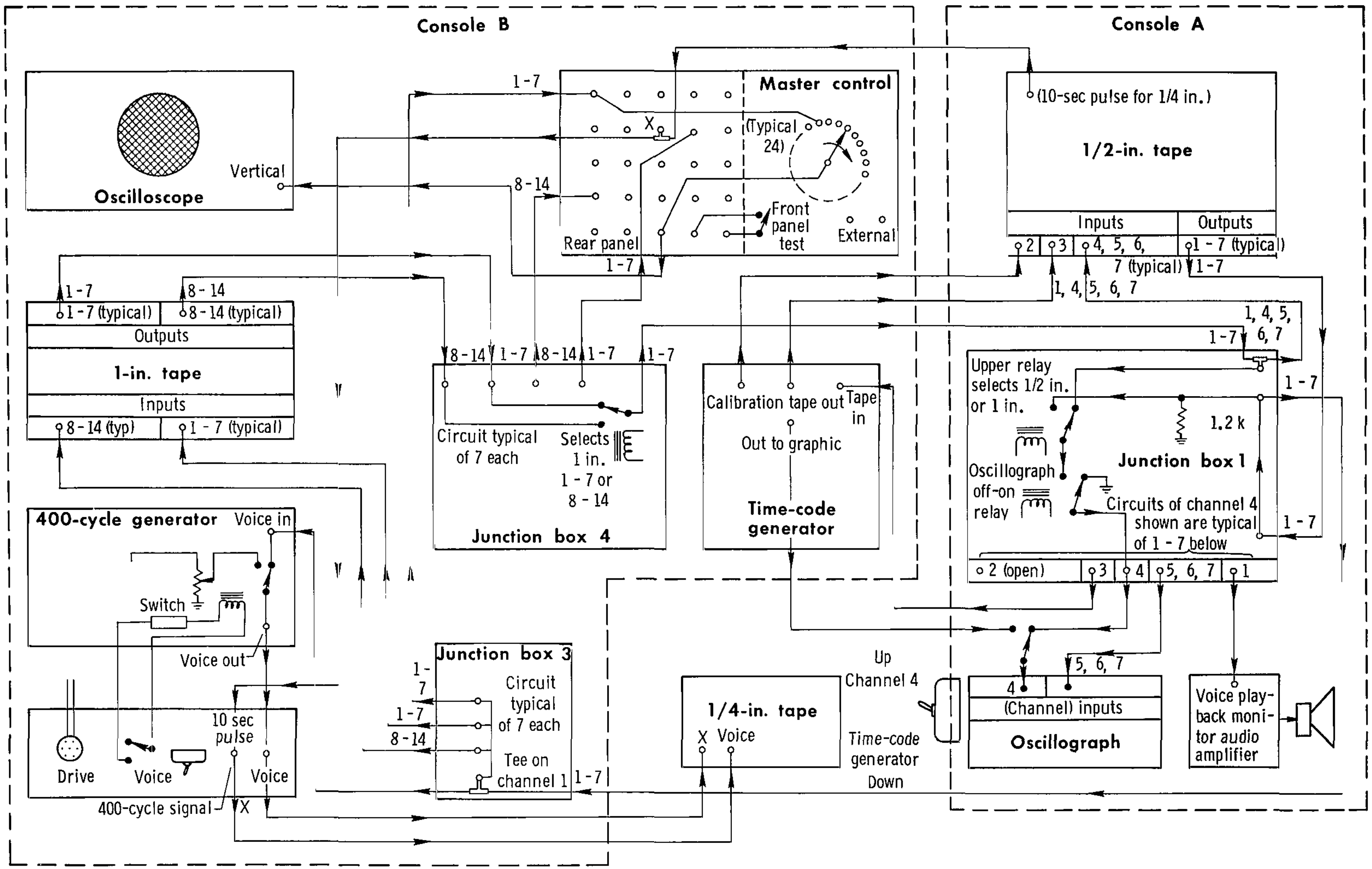


Figure 2.– Block diagram of the FM data-handling facility.

The secondary tape is recorded in fast time or real time, depending on requirements. The facility is designed to allow, by pushbutton control, dubbing in real time, four times real time, or eight times real time. The fast-time feature allows much faster entry into the analog-to-digital converter and consequently reduces the equipment usage time both at the dubbing facility and at the analog-to-digital converter. The four-times-real-time dubbing mode is used when it is desired to dub the voice channel since, at greater speeds, the frequency content of the audio channel is lost and cannot be replaced. Thus, the eight-times-real-time dubbing mode is rarely used, since most flight tapes contain a voice channel. The time code is keyed to start with the first electrocardiographic (ECG) waveform and is dubbed onto the primary tape (raw flight tape) and then recorded automatically onto the secondary tape. This analog time code, which is in Inter Range Instrumentation Group (IRIG) Code B, is later converted to the NASA 36-bit digital time code during analog-to-digital conversion. The time-code carrier frequency is also dubbed onto a separate channel on the primary tape and then automatically recorded onto the secondary tape. This 1,000-hertz signal, rather than a free-running clock, is used by the analog-to-digital converter to lock the digital sampling rate to the time base dubbed on the original flight data. Also, the electrocardiographic signal is simultaneously dubbed on two separate channels of the primary tape to provide a means of isolating malfunctions through the entire system and to provide data redundancy in the event of channel failure. Thus, seven channels of information are transferred from the primary to the secondary tape, as follows:

Channel	Data type
1	Voice
2	Time-code carrier
3	Time code
4	ECG
5	ECG
6	Pneumotachometer
7	Acceleration

The FM handling system contains a selector switch connected to the output of each of the tape decks and provides a means for displaying the data on an oscilloscope. This allows immediate and continuous data quality checks at each discrimination point during the FM handling process. The operator, by selecting all channels periodically during the handling operation, is able to compare the raw data with the dubbed data and thus rapidly assess system performance and immediately spot any malfunctions. The operator is instructed to exercise extreme caution in monitoring for system malfunction, since erroneous data from this point would be unnecessarily processed downstream on the analog-to-digital converters.

Channels 1 to 7 on the secondary tape are used to record one flight, then the secondary tape is rewound and channels 8 to 14 are used for a second flight recording. This procedure allows simultaneous entry into the analog-to-digital converters of two flights in fast time. Further, the FM reproduce unit feeding the analog-to-digital converter is played back twice as fast as the secondary tape was recorded. Thus, routinely, these flight data were processed at the analog-to-digital facility at eight times real time, two flights at a time. Since all flight data were recorded twice and played back three times before analog-to-digital conversion, it was necessary to carefully design the FM facility to guard against accumulative noise. To further minimize the degradation of the 37-dB signal-to-noise ratio maintained during data collection, it was necessary to process at a greater signal-to-noise ratio at each of the successive record and playback stations. This was accomplished by driving each tape deck at a higher speed than the preceding deck, and selecting each speed so that the processing signal-to-noise ratio was improved over that of the preceding tape speed. This technique of increasing tape speeds, combined with the requirement to maintain standard IRIG frequencies and speeds and the dubbing-in-fast-time mode, as well as consideration of tape cost, led to the selection of the following FM facilities, tape speed, and center frequency format:

Analog data-handling equipment		Analog record and playback characteristics			Time code and reference signal		4-channel paper-chart recorder
		Speed, ips	Frequency response, kHz	Center frequency, kHz	Reference, kHz	Time code, kHz	Paper speed, mm/sec
Airborne biomedical recorder (1/2-inch; battery powered; average recording time, 100 minutes record only)		15/16	0 to 0.1 FM[1] 0.3 to 1.5 D[2]	0.843	-	-	-------
Tape transport (1/2-inch tape; 10.5-inch reels, record and playback)	Real time	15/16	0 to 0.156 FM 0.05 to 3.75 D	0.843	-	-	10
	4 times real time	3 3/4	0 to 1.25 FM 0.05 to 15 D	3.372	4	4	25 or 50
Tape transport (1-inch tape; 10.5-inch reels, record and playback)	Real time	1 7/8	0 to 0.625 FM 0.05 to 10 D	3.372	1	1	10
	4 times real time	7 1/2	0 to 2.5 FM 0.05 to 38 D	13.5	4	4	25 or 50
Analog input to analog-to-digital conversion equipment	Real time	1 7/8	0 to 1.25 FM 0.05 to 19 D	3.372	-	-	-------
	8 times real time	15	0 to 5 FM 0.1 to 75 D	27	-	-	-------
Voice recorder, 1/4-inch binaural tape	Real time	1 7/8	0.04 to 6 D	-----	-	-	-------
	4 times real time	7 1/2	0.03 to 18 D	-----	-	-	-------

[1]FM denotes frequency-modulation mode
[2]D denotes direct mode

The voice channel was not reduced digitally but was played back in real time by an operator who annotated both the comments in flight and the time of the comment. Figure 3 shows an example of the digitally computed and plotted flight data. This processing (not discussed in this paper) is done after the analog-to-digital conversion. The voice comments of the pilot are plotted against minute averages of physiological data. The comments are then lettered on the physiological-data plots to make it possible to estimate the correlation between physiological response and the mission or maneuver the pilot was performing. This process was extremely time-consuming, but it was believed that trends in these physiological data would be better understood if the pilot's comments were available for comparison. The voice annotator played back the raw-data tape (primary tape) on a less-expensive instrument than that of the operational FM facility and, in this manner, did not interfere with the secondary-tape logistics or with the workload of the FM handling facility.

As a courtesy to the student pilots being monitored, a separate recording was made of the voice channel during the dubbing operation on 1/4-inch, 2-channel tape; one channel contained the voice and the other a simplified time code. These tapes and small portable playback machines were made available to the pilot for later reference.

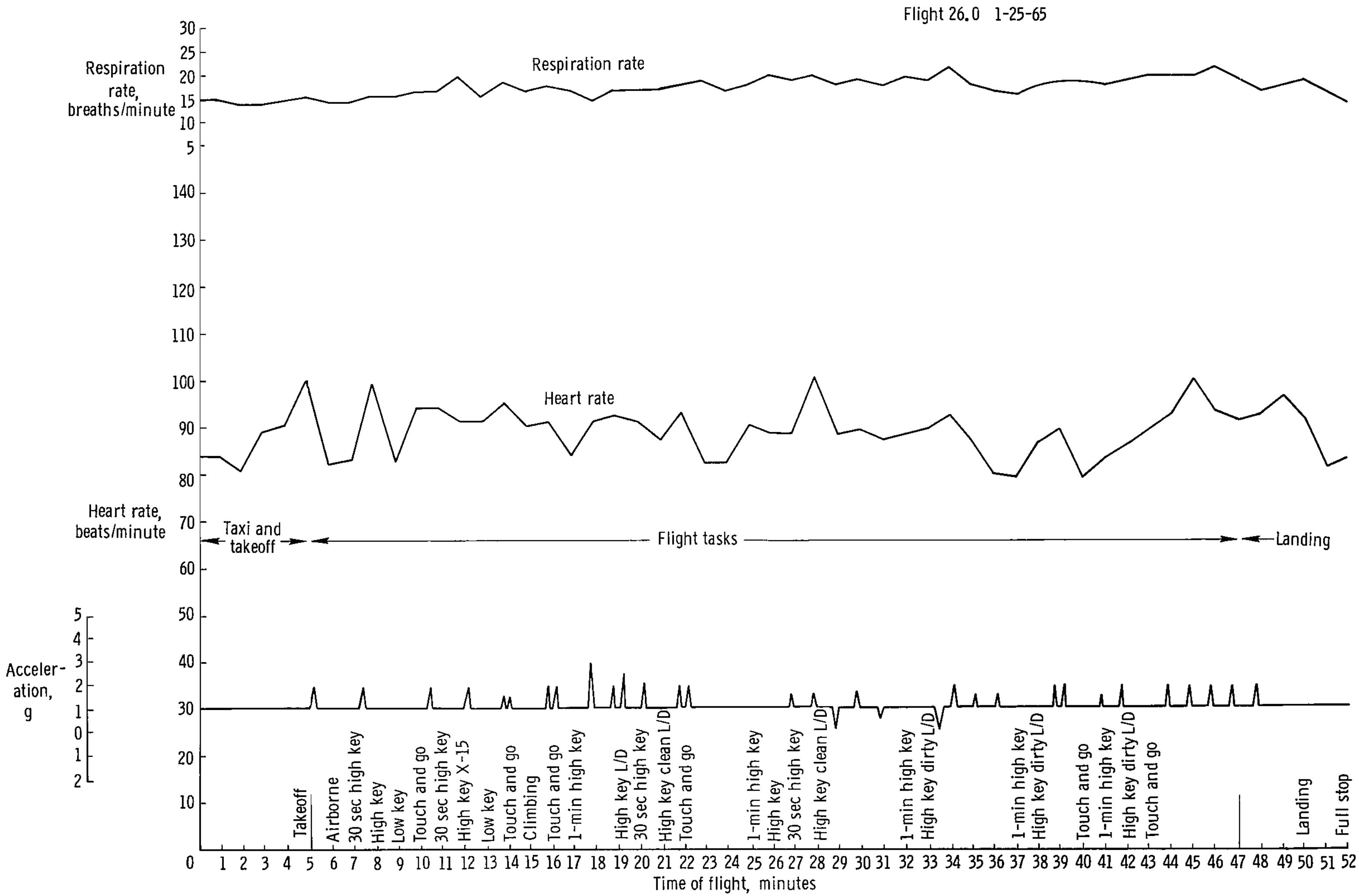


Figure 3.– Digitally computed results of a flight, including voice comments.

Analog-to-Digital Conversion Facility

The analog-to-digital conversion facility receives the IRIG standard, 14-track, 10 1/2-inch-diameter instrumentation analog tapes dubbed from the original 7-track test tapes recorded at 15/16 inch per second. Each of the secondary tapes contains eight channels of data to be digitized and two channels of 1 kHz (real time) carrier for locking the sampling rate to the time code.

The eight channels of data consist of two electrocardiogram, two respiration rate, two acceleration, and two time code (standard IRIG Code B). The sampling-rate requirements were established as 300 samples per second for ECG, 10 samples per second for each channel of respiration and acceleration, and 250 samples per second for the time code, all at 8 bits per sample, minimum. To accomplish this sampling rate, a multiplexing/sampling arrangement was designed (fig. 4) using 12 commutator points and an 8-kHz clock from the time-code track of the tape. As indicated in the following table, the multiplexer had 18 pins, and each pin represented a 12-bit group. Each pin was sampled at 1-millisecond intervals. The acceleration and pneumotachometer were each sampled every 18 milliseconds. The open channel and the electrocardiographic channel were sampled six times during every 18 milliseconds, corresponding to a sample every 3 milliseconds. This sampling rate was considered adequate for electrocardiographic frequencies from dc to 100 cps and for respiration and acceleration frequencies from dc to 25 cps. As much wide-band filtering as possible, without destroying intelligence, is done subsequent to the multiplexer (fig. 4), since to digitally filter in the computer is costly. The multiplexer format and filter values selected were as follows:

Multiplexer pin	Channels 1 to 7	Channels 8 to 14	Low-pass output filter value, Hz	Real-time filter value, Hz
1	5 ECG	12 ECG	450	56
2	7 accelerometers	14 accelerometers	80	10
3	4 open	11 open	Open	---
4	5 ECG	12 ECG	450	56
5	6 pneumotachometers	13 pneumotachometers	20	2.5
6	4 open	11 open	Open	---
7	5 ECG	12 ECG	450	56
8	Ground	Ground	----	---
9	4 open	11 open	Open	---
10	5 ECG	12 ECG	450	56
11	Ground	Ground	----	---
12	4 open	11 open	Open	---
13	5 ECG	12 ECG	450	56
14	Ground	Ground	----	---
15	4 open	11 open	Open	---
16	5 ECG	12 ECG	450	56
17	Ground	Ground	----	---
18	4 open	11 open	Open	---

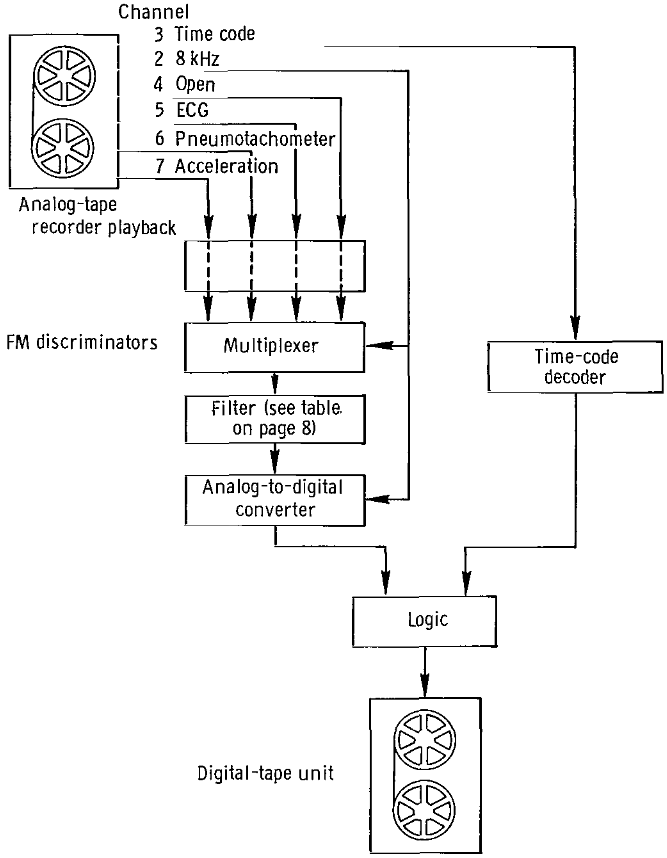


Figure 4.– Block diagram of analog-to-digital conversion system.

The open channel shown in figure 4 carried the spare ECG through the FM portion of the system, however, this channel is carried throughout the digital system, including the computer reduction program, as an open channel to allow for expansion to another parameter.

The analog tapes are received at the analog-to-digital facility from the FM data-handling facility with IRIG Code B time code on channels 3 and 10 (fig. 4). Only binary coded decimal time is included in this format option. A special patch board for the time-code decoder was developed for this program. The decoder places the time code and milliseconds information on the magnetic tape in NASA 36-bit format. The analog-to-digital converter has a feature that enables start-and-stop times to be called by time code and conversion controlled by the time-code decoder, which allows selective portions of flight tapes to be converted for research purposes. During the dubbing process, the time code does not start to increase in value until the data portion of the tapes has been reached. This allows automatic startup as soon as the data are reached. A modification of this procedure was required because of a "flywheel" feature of the time-code decoder that allows reading through timing dropouts. This feature causes the 1-second indicator to appear intermittently prior to the data. Therefore, the automatic start is set to a +3 seconds to prevent false startup. The time generator at the FM facility is always reset to zero after the calibration signals are dubbed, thus the decoder follows this change and the computer recognizes the change as the start of data.

As shown in figure 4, after multiplexing and filtering, the data are fed through the analog-to-digital converter and recorded on digital tapes. These tapes contain three calibration files in the standard multiplex format. The first file is upper band-edge calibration, the second file is center frequency calibration, and the third file is lower band-edge calibration. This arrangement allows automatic data reduction based on the preflight calibration. The calibration section in the analog tape is processed in the same file as the flight data and is distinguished by time code.

The digital output tapes contain 121, 36-bit words in standard IBM binary tape format at 800 bits per inch. The first 120 words consist of three 12-bit data samples, and the 121st word contains range times. The specific output format is represented by 11 bits (absolute binary magnitude) plus algebraic sign (±10 volts = ±1023).

The following specifications were established for analog-to-digital conversion of the flight data (ref. 2):

Analog tape speed - 15 inches per second

Discriminator center frequency - 27 kHz

Reproduce heads - IRIG

Digital tape density - 800 bits per inch

Clock rate - 8 kHz tape derived

Sampling mode - bipolar

Data-quality monitoring was strictly enforced at the analog-to-digital conversion facility, since any "bad" data through this point could cause many hours of computer operating time to be spent unnecessarily. The quality monitoring points defined and used were:

Monitoring the FM discriminator output.

Monitoring the analog tape-speed variation.

Monitoring the sampling and synchronization pulse in the multiplexer.

Observing sample rate signals.

Providing for converting from digital-to-analog from the digital tapes produced (oscillographic records).

Monitoring parity, incomplete word, and record on check panel.

Continuous reading of the digitized time-code signal.

With these checks established, the problems in the analog-to-digital system were detected before the results were processed by the computer, which also allowed a secondary checkpoint for detecting bad data that had been missed at the FM handling facility.

DISCUSSION

The initial design approach discussed in the preceding section allowed administrative decisions on the advisability of purchasing or renting equipment to be made early in the program. The unique nature of the biomedical data dictated that a special FM handling facility be purchased but that the analog-to-digital conversion equipment be rented. Since the output of the FM handling facility was in standard format, a reasonable price for analog-to-digital conversion was obtained.

The total time the equipment was used for FM handling and analog-to-digital conversion for each flight averaged 31 minutes 15 seconds. Each flight had an average duration of 100 minutes. By processing on the FM facility at four times real time, the secondary tape was prepared in 25 minutes and each flight at the analog-to-digital facility required 6.25 minutes (two flights were processed simultaneously and at eight times real time). Thus, the FM and analog-to-digital handling procedure was performed with approximately 520 hours of processing time for more than 1,400 flight hours of data. The processing at the FM and analog-to-digital facilities was accomplished, without exception, at a signal-to-noise ratio greater than 40 dB, which minimized data quality degradation since the data entered the FM facility at a signal-to-noise ratio of not less than 37 dB.

This facility has been operating successfully since October 1965 and has required only daily preventive maintenance, such as cleaning tape decks and demagnetizing tape heads.

This system is suitable for the preparation of biomedical data for digital processing, since the system design can be generalized to accommodate different data-input characteristics, and the system output characteristics are standard.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., December 29, 1967,
127-49-06-02-24.

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